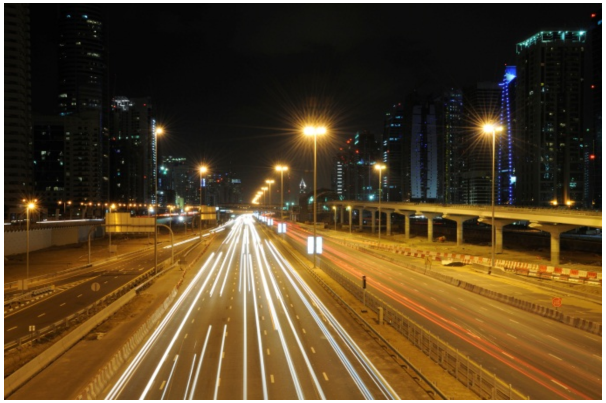


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Rethinking Luminaires

Using Glass as a Value-Added Lens Component for LED Lighting Applications

David P. Maikowski, Guardian Industries Corp.

DOE SSL R&D Workshop LED Panel

Tampa, FL

January 29, 2014

GUARDIAN
Glass • Automotive • Building Products

Contents

- Historical Use and Positives/Negatives of Using Glass Lenses in Lighting
- Options for Minimizing Absorption and Reflection Losses
- Options for Reducing Angular Losses
- Options for Minimizing Dirt and Debris Losses
- Challenge of Using LED Lighting in Harsh Outdoor Environments
- Concept of Heatable Glass Lenses and Design Options
- Summary/Conclusions

What's Common in These Historical Luminaires?

They all used glass as their optical lens between the light source and the external environment

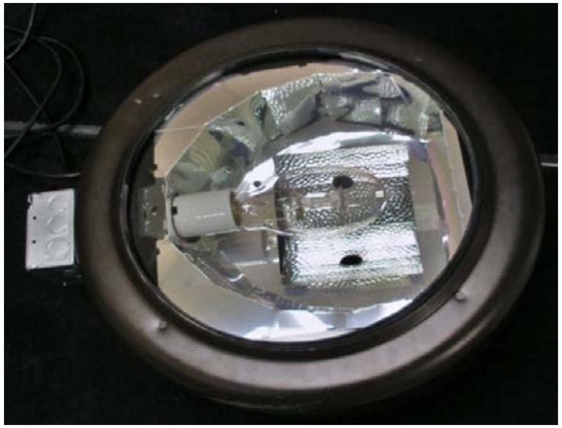
Historical Benefits of Using Glass in Lighting

- **Mechanical Strength and Durability**
  - > Strengthened (tempered) glass has successfully been fielded in outdoor lighting applications for > 50 years to provide translucent properties as well as long-term mechanical strength and durability (thermal, chemical, and environmental)
- **Environmental Protection**
  - > Glass has proved to be the best long-term material choice to protect the valuable components of a lighting fixture (light source, reflectors, electronics, etc.) from the elements in outdoor lighting applications
  - > Unlike other materials, glass does not carry a static charge that attracts dirt
- **UV Resistance**
  - > Glass does not degrade to the intense and prolonged UV exposure seen in outdoor lighting applications
- **Cost and Sourcing**
  - > Glass is a low-cost and readily available material option
- **Flexibility**
  - > Glass can be easily and cost-effectively converted into end fabricated parts based on the lighting application's need

LEDs Change the Role of Glass in Lighting

- **The adoption of LED-based lighting has triggered a major change in how optics are managed in lighting fixtures**
  - > With traditional Incandescent and HID-based light sources, light is illuminated from one single light source multi-directionally and directions/distribution patterns are managed with reflector assemblies
    - > High levels of UV and IR energy generated especially at > 1,000W sources
  - > With LED-based light sources, light is illuminated from multiple (e.g., 60 – 120) light sources with individual primary optics required over each LED source to deliver light in the intended distribution pattern
    - > Lower energy consumption and low levels of IR energy (heat) generated
    - > PMMA Acrylic primary optic lenses are now fundamental and critical part of optical design

HID Fixture with Single Light Source and Reflectors



LED Fixture with Multiple Light Sources and Individual “Nano” Optics

Glass and LED SSL

- **The LED "revolution" in lighting in the past 10 years has forced new rules for luminaire design, performance, cost, and sourcing**
- **Plastic content, due to the optical needs of managing multiple light sources (LEDs), is now a functional need and not a choice**
  - **Plastic primary optic is now needed** to reach needed light distributions
  - PMMA Acrylic material and its converters/manufacturers have improved quality and durability allowing it to be used as a standalone lens barrier
- **Glass is no longer absolutely needed in traditional application areas of outdoor and industrial lighting – esp. when LEDs are increasingly being used**
  - Now often a **"design option**" in LED luminaires
  - Primary use is in HID applications where glass is needed for UV resistance
- **Does glass have a place of value in LED lighting?**
  - Glass creates value in areas where LED luminaires cannot provide the same functions that traditional lighting technologies did
  - These areas include areas of harsh environments where exposure to UV or IR wavelengths are required to provide high levels of illumination and plastic materials cannot survive long-term without degrading and sacrificing light transmission

Glass and The Lighting Market

The fact is that numerous applications in the lighting market would benefit from high-performance glass lenses that maximize fixture efficiency/efficacy while providing mechanical strength and environmental durability

Sports Lighting

Roadway Lighting

Industrial Lighting

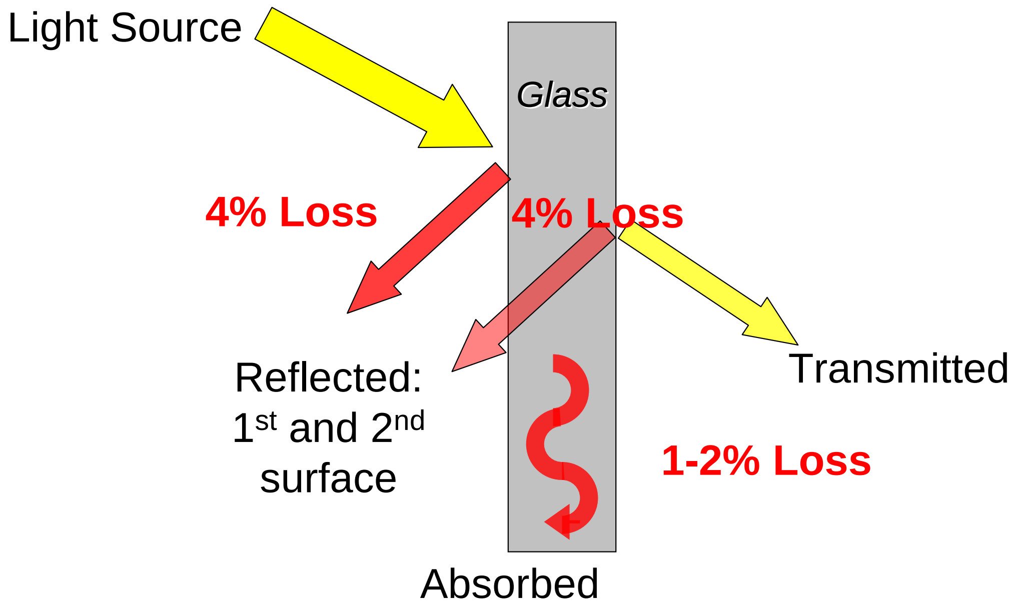
Flood and Area Lighting

GUARDIAN

Glass • Automotive • Building Products

Historical Challenge of Using Glass in Lighting

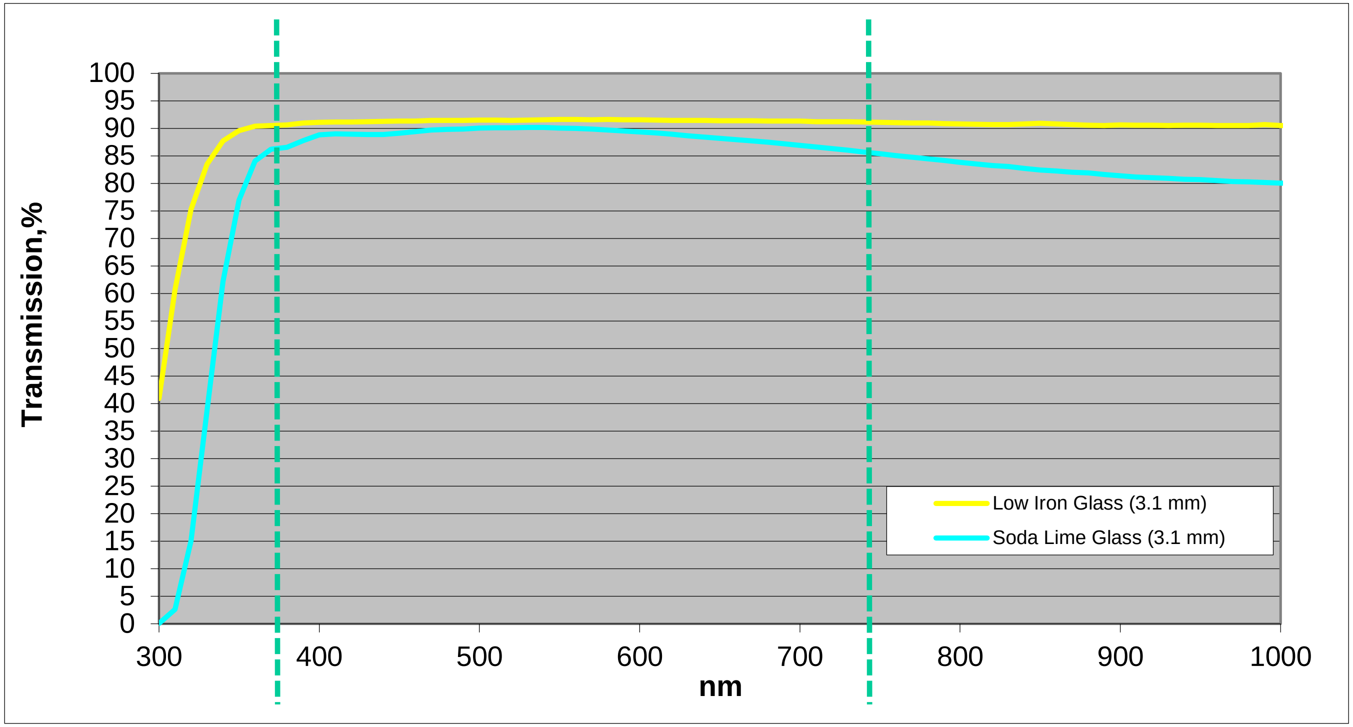
The historical challenge of using a glass lens in lighting applications has been with efficiency losses due to light reflection and absorption (shown in red below).



- Glass loses 9-10% of transmitted light by its material properties alone
- Therefore, you must **minimize absorption**, **increase light capture** or transmission, and **minimize reflection** on the glass to overcome this challenge and maximize the light going through the glass lens
- How? Through optimized glass **chemistries** and **coatings**

Reducing Absorption Losses with Low-Iron Glass

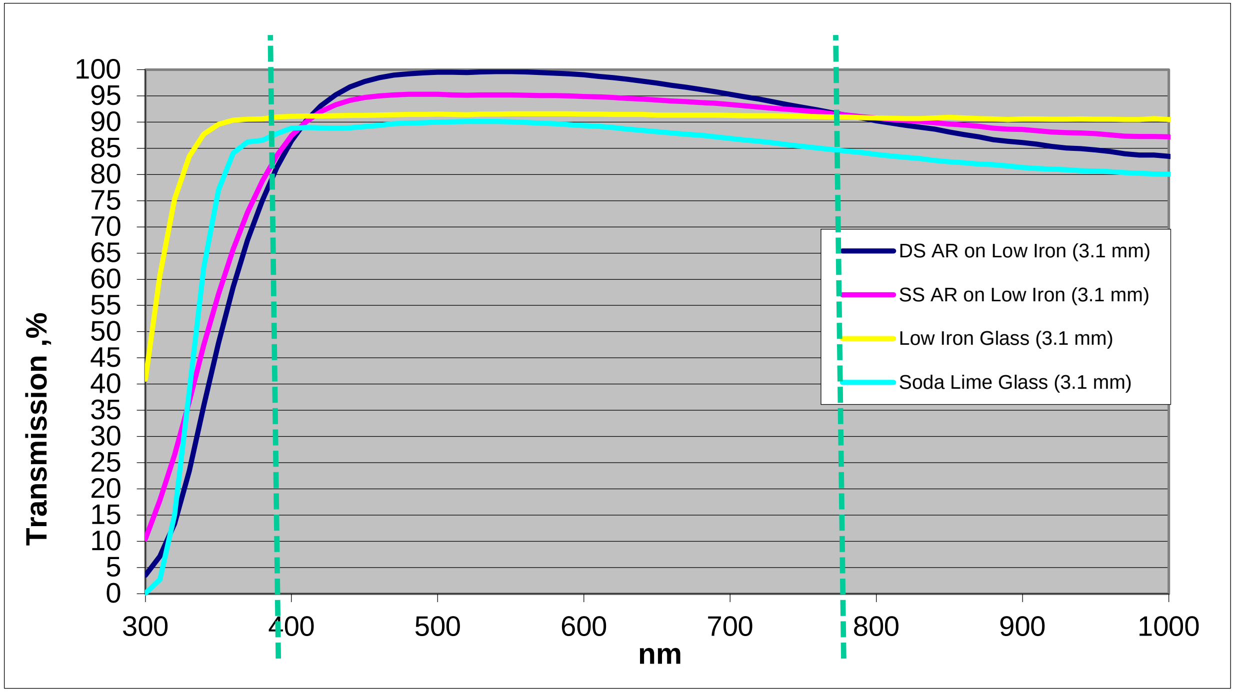
Standard soda lime float glass contains 0.11 – 0.08% Fe_2O_3 which allows 2% of visible light's energy to be absorbed and lost within the bulk material itself



In contrast, "Low Iron" glass contains only 0.02 – 0.03% Fe2O3 which **all but eliminates absorption losses** in the visible spectrum typically seen with glass lenses

Reducing Reflection Losses with AR Coatings

Anti-Reflective (AR) Coatings minimize the interference of light traveling through a given material's surface by creating a filtering layer with a refractive index (n) as close to air (n= 1) and the lens material itself (glass n= 1.52)



AR coatings can **reduce glass reflection losses to 0.5% per side** and, when coupled with low-iron glass to reduce absorption losses, **can increase transmission** levels of glass lenses from 89% (soda lime float glass) **to 99%** (Double-Sided AR on Low Iron glass) in the visible range at NADIR

GUARDIAN
Glass • Automotive • Building Products

Using AR Glass to Increase Total Lumen Output

	Uncoated	SS AR	% Gain	DS AR	% Gain
Sample 1 - Significant Incident Angles <30^0	5984.7	6568.1	9.75%	6702.0	11.99%
30-90^0 Incident Angle Zonal lumens	3239.7	3534.9	9.11%	3585.5	10.67%
0-30^0 Incident Angle Zonal lumens	2746.4	3030.6	10.35%	3119.9	13.60%
Sample 2 - Mixed Incident Angles	6918.7	7091.7	2.50%	7224.5	4.42%
30-90^0 Incident Angle Zonal lumens	6124.0	6286.2	2.65%	6395.3	4.43%
0-30^0 Incident Angle Zonal lumens	797.8	808.7	1.37%	832.5	4.35%
Sample 3 - Dominant Incident Angles <30^0	4378.7	4704.4	7.44%	4814.0	9.94%
30-90^0 Incident Angle Zonal lumens	3089.1	3349.2	8.42%	3390.4	9.75%
0-30^0 Incident Angle Zonal lumens	1291.1	1357.4	5.14%	1425.9	10.44%
Sample 4 - Significant Incident Angles <30^0	6972.0	7858.5	12.72%	8213.1	17.80%
30-90^0 Incident Angle Zonal lumens	4451.8	5040.9	13.23%	5187.0	16.51%
0-30^0 Incident Angle Zonal lumens	2523.4	2821.7	11.82%	3028.9	20.03%
Sample 5 – Mixed Incident Angles	4029.4	4224.4	4.84%	4385.2	8.83%
30-90^0 Incident Angle Zonal lumens	3560.8	3733.4	4.85%	3884.0	9.08%
0-30^0 Incident Angle Zonal lumens	469.7	492.1	4.77%	502.4	6.96%

Results indicate that **the greater the dominance of low incident angles (<30°) between the source and first surface of the glass cover, the greater the gain in total light production (lumens)**.

GUARDIAN
Glass • Automotive • Building Products

Using AR Glass for Fixture Count Reduction

Here we have a baseball playing field lighting system comprised of 6 poles utilizing 44 total luminaires is reduced to 40 luminaires by the 10% optical efficiency gains realized from DS AR glass

	Soda Lime Glass	DS AR on Low Iron
Fixture Cost	$ 177.89	$ 199.89
Fixture count	44	40
Total luminaire cost	$ 7,827.16	$ 7,995.60
Annual Energy Cost*	$ 2,833.60	$ 2,576.00
Annual savings		$ 257.60
Payback period (years)		0.65

The **additional cost of coated glass over soda-lime glass produces a payback of less than one year.**

GUARDIAN
Glass • Automotive • Building Products

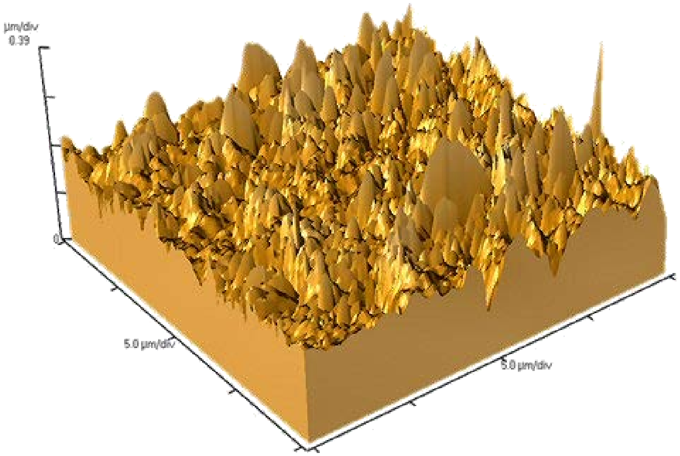
Using Hydrophilic Coatings to Reduce Dirt and Debris Losses

- Glass appears to be smooth, stable and chemically inert.
- However, glass is actually:
  - > Microscopically rough
  - > Chemically reactive
- Since the surface of glass is highly reactive, these environmental conditions alter its surface:
  - > Chemical attacks
  - > Humidity
  - > Temperature
  - > Dirt and Debris Build-up and Adhesion
- Plastics face many of these same challenges as additives/dopants cause them to become brittle and rough over time

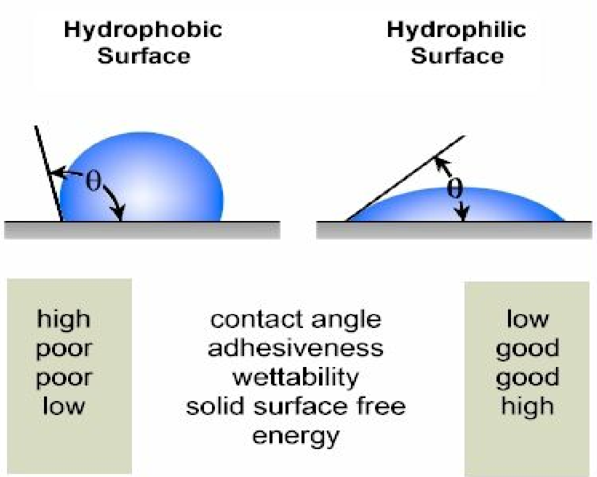
New Glass Surface

The Need For Protection

- Untreated glass is susceptible to damage and aging effects when exposed to:
  - > Moisture and heat
  - > Airborne organics
  - > Alkaline agents
  - > Cleaning residues
- The glass surface chemically corrodes and becomes rough
  - > Promotes Hydrophobic behavior
- Allows for dirt and debris to easily attach and adhere
  - > Dirt and debris build-up
  - > Worse on plastics where static charge is inherently higher
- Dirt and debris build-up is a huge problem for outdoor light fixtures
  - > Nearly 30% light loss seen in field due to dirt depreciation over a luminaire's lifetime

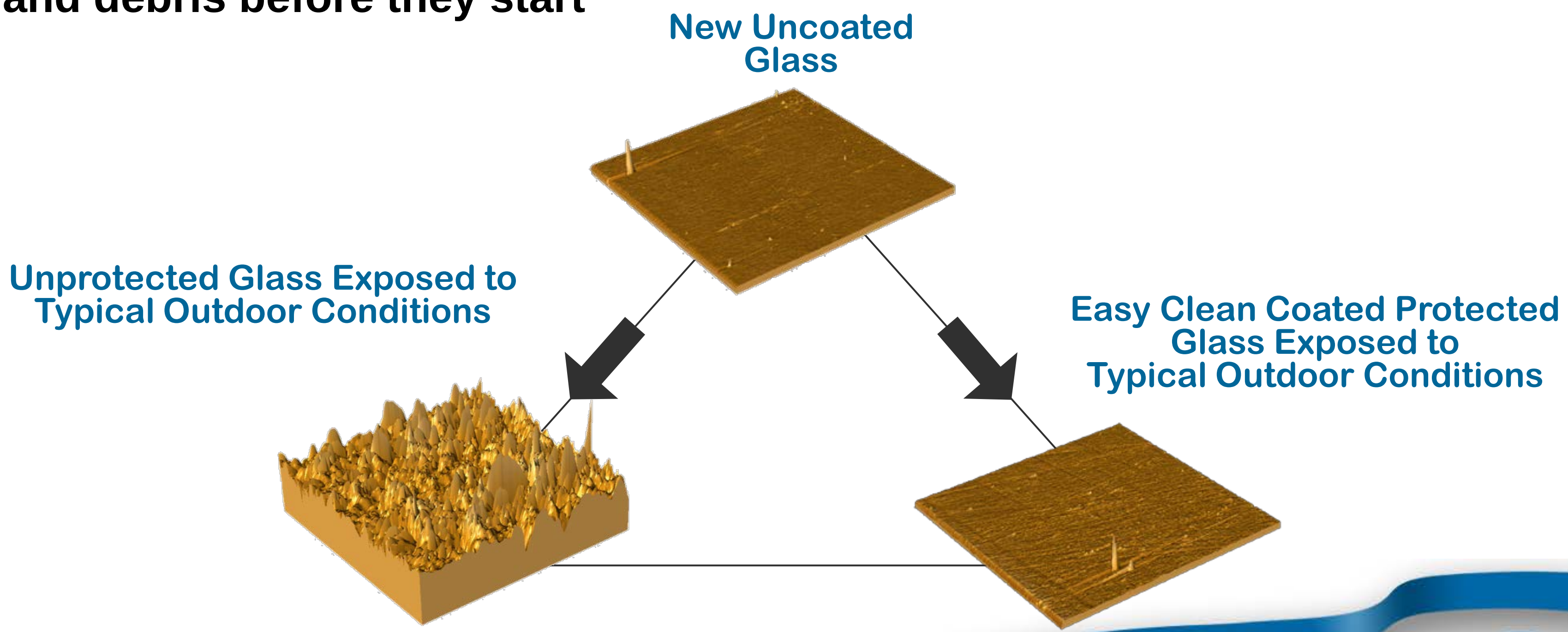


Unprotected Glass Exposed to Environmental Conditions



Reducing Dirt/Debris Losses Through Coatings

- **A ion-infused Hydrophilic coating is <u>fused</u> to the glass' surface, providing:**
  - > An excellent corrosion barrier
  - > High degree of chemical stability
  - > Embedded long-term protection (e.g. long-life RainX)
  - > Resistance towards glass contaminants
  - > Low coefficient of friction…ultra smooth surface for easy cleaning
- **It seals the glass' surface, stopping corrosion and crevices for housing dirt and debris before they start**



GUARDIAN
Glass • Automotive • Building Products

Reducing Angular Losses with Surface Treatments

- **Standard glass and plastics cannot help capture light over angle and reduce efficiency losses over angle**
  - > However, glass that has been treated with an acid-etch treatment or processed through a “rolled” pattern can help increase light capture and reduce losses over angle

Comparison By Degrees

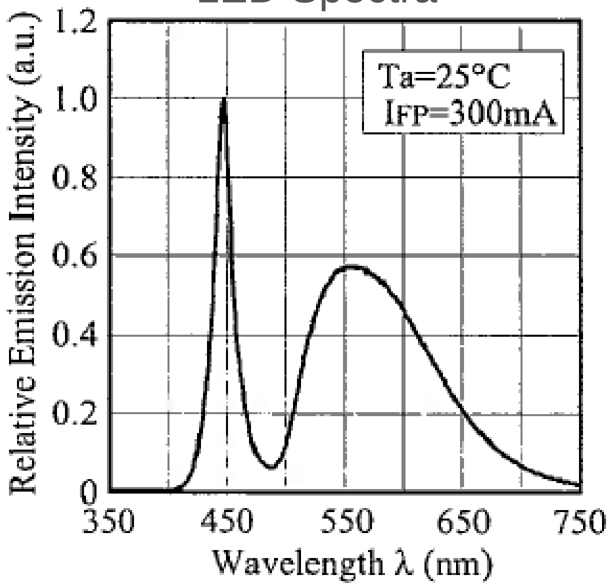
Diffuser/Lens	Angle of Light Source - Incidence to Face of Diffuser Material - Readings in Footcandles													
	0^0	Comp to Pattern 12 Acrylic	10^0	Comp to Pattern 12 Acrylic	20^0	Comp to Pattern 12 Acrylic	30^0	Comp to Pattern 12 Acrylic	40^0	Comp to Pattern 12 Acrylic	50^0	Comp to Pattern 12 Acrylic	60^0	Comp to Pattern 12 Acrylic
Pattern 12 Acrylic	**32**	REF	**25.8**	REF	**19.1**	REF	**13.5**	REF	**9.7**	REF	**6.9**	REF	**5.6**	REF
Acid-Etch with SSAR	34.3	**107.2%**	28.3	**109.7%**	19.3	**101.0%**	13.3	**98.5%**	9.8	**101.0%**	6.8	**98.6%**	4.8	**85.7%**
Tetra Pattern	35.1	**109.7%**	27.4	**106.2%**	19.7	**103.1%**	13.5	**100.0%**	9.9	**102.1%**	6.7	**97.1%**	4.7	**83.9%**
Dew Pattern	42.1	**131.6%**	32.2	**124.8%**	20.1	**105.2%**	13	**96.3%**	10.1	**104.1%**	7.9	**114.5%**	6	**107.1%**
Prismatic Pattern with SSAR	41.9	**130.9%**	32.9	**127.5%**	20.4	**106.8%**	13.3	**98.5%**	10.3	**106.2%**	8.2	**118.8%**	5.9	**105.4%**
Matte Pattern	45.7	**142.8%**	34.6	**134.1%**	20.7	**108.4%**	12.9	**95.6%**	10.5	**108.2%**	8.5	**123.2%**	7.3	**130.4%**

- **In all cases, the glass solution provides superior performance over the Pattern 12 Acrylic baseline in this example**

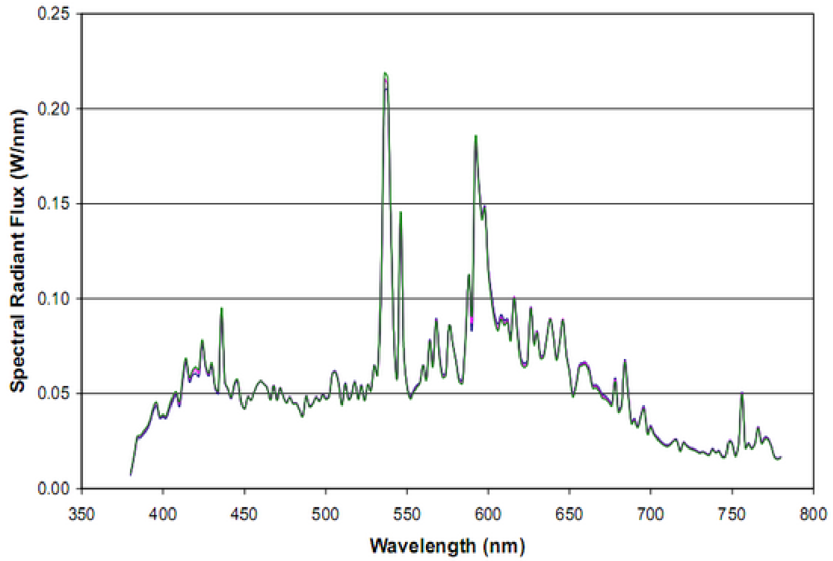
GUARDIAN
Glass • Automotive • Building Products

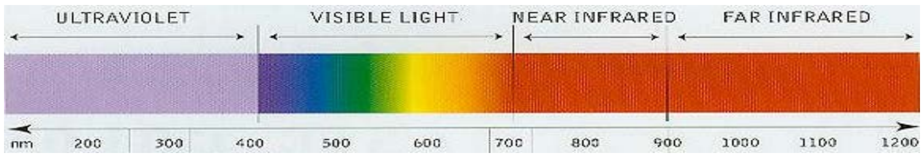
Challenges of LED Lighting in Outdoor Use

LED Spectra



HID (Metal Halide) Spectra





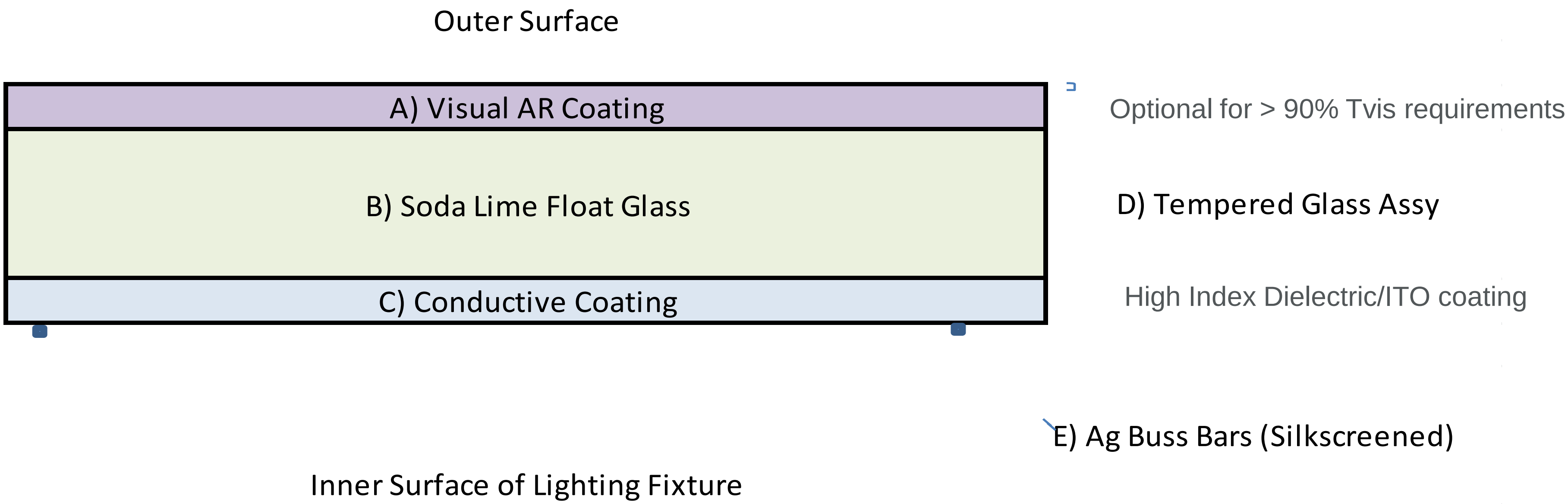
- **LED source clearly does not generate high levels of IR energy**
  - OK for luminaires that do not see harsh environments
  - **Not OK for luminaries <u>required to melt snow and ice off</u>** of them in harsh environments (as HID has done in the past)
- **How can we bridge this gap? Through heating the lens!**

GUARDIAN
Glass • Automotive • Building Products

Material Options for Heatable Lenses

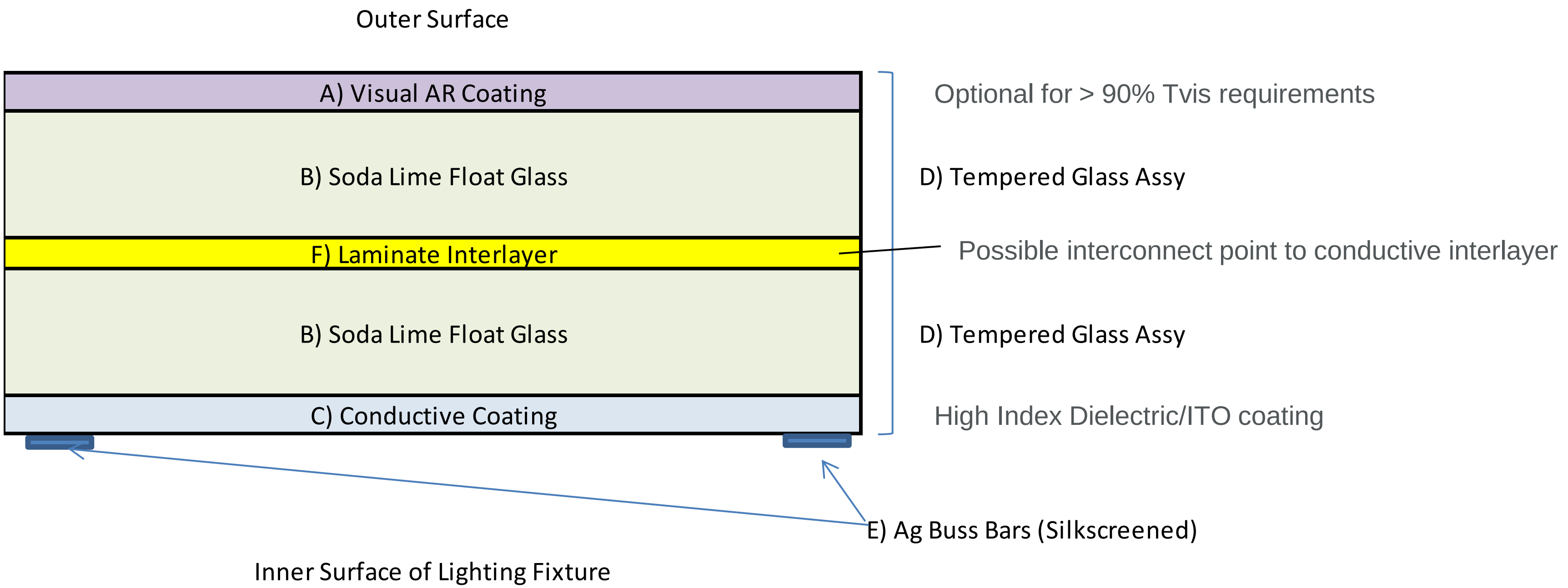
- **Plastic?**
  - **Plastics (PMMA or Polycarbonate) cannot be a cost-effective option** due to temperature limitations vs. material degradation
    - Would require costly dopants that would negatively impact efficacy and would still sacrifice transmission (efficiency) over lifetime
- **Glass?**
    - Al-Enriched or “Gorilla” glass is cost-prohibitive and typically very thin and susceptible to breakage (even when chemically strengthened)
    - Soda Lime and Borosilicate Glass are viable technical and economical options
      - Borosilicate glass is strong and inert but is costly with long lead-times and fabrication challenges (thermal or chemical strengthening)
      - **Soda Lime glass can cost-effectively meet the need using different technologies and fabrication options**
        - Transparent Conductive Coatings (TCC) can be applied via in-line pyrolysis (SnO2:Fl) or MSVD (ITO) “Sputter” processes
        - Conductive Laminate Interlayer (coated with conductive layer or with embedded Tungsten “wiggle wire”) can be used but can be costly and/or negatively impact efficacy and creates larger interconnect challenges

Heatable Glass Lens Concept (Monolithic)



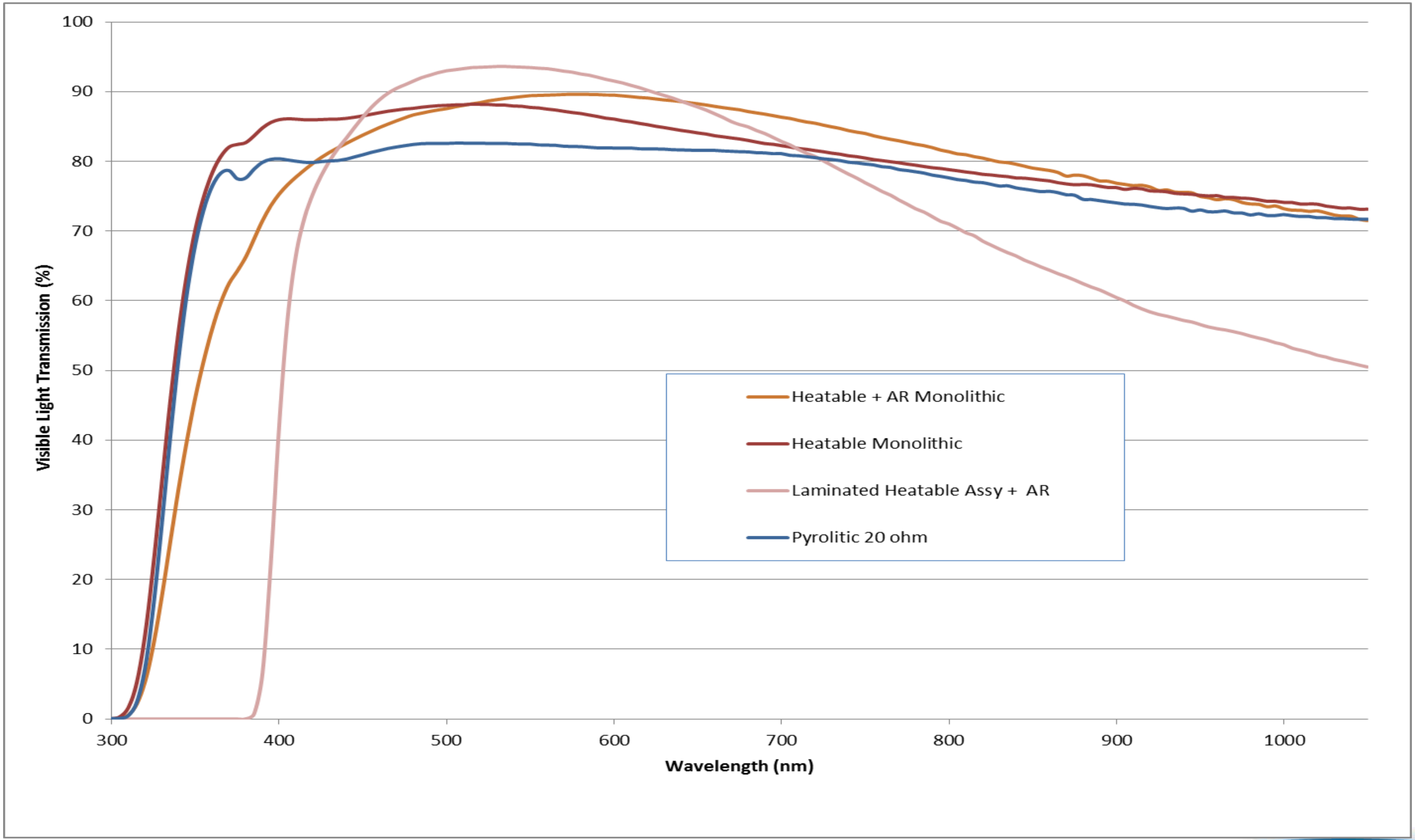
- The **Monolithic Configuration** is used for applications where **thickness profile** is of concern and where **increased glass strength (thermally tempered to 25,000 psi) is needed for durability and blunt force** resistance
    - No exposure to projectiles

Heatable Glass Lens Concept (Assembly)



- **Assembly Configuration** is used for applications where lens with **exposure to projectile impact and where safety is required**
  - Keeps glass lens intact with **laminated interlayer to protect the light source and prevent broken glass fragments** (similar to automotive windshields)
  - Laminated interlayer (index matching for high transmission) can serve as the safety layer with or without conductive agent within it
    - Coating in close proximity can also do the job and makes interconnect easier

Heatable Glass Optical Properties



Summary/Conclusions

- The continued push for widespread adoption of Solid State Lighting (SSL) across all market is creating both opportunities and challenges for all of us
- Glass has been a reliable and valuable material throughout the history of artificial lighting and can still provide it going forward when used in innovative and novel ways in SSL
- Using different glass chemistries, surface treatments, fabrication/conversion processes, and coatings can allow a SSL luminaire to reach even higher levels of performance, efficiency, and application fields
- No material is perfect, but glass is a proven material in outdoor applications (including commercial luminaires) and can easily be coupled with the new "primary" plastic optics technology to create both superior performance, value, and reliability

Contact Information

David P. Maikowski

Market Director, Industrial Electronics Glass

Guardian Industries Corp.
Science & Technology Center

14511 Romine Road

Carleton, MI 48117

Phone: +1 (734) 654-4720

Email: dmaikowski@guardian.com

An overview of Guardian Industries' lighting solutions can be found on-line at:

http://www.guardian.com/GuardianGlass/glassproducts/TechnicalGlass/lightingproducts/index.htm

Thanks for your time and attention!